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RESEARCH MEMORANDUM

CHARTS FOR ESTIMATION OF THE PROFILE DRAG-LIFT RATIO OF A HELICOPTER ROTOR HAVING RECTANGULAR BLADES WITH -8° TWIST

By F. B. Gustafson

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
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CHARTS FOR ESTIMATION OF THE PROFILE DRAG-LIFT RATIO OF A HELICOPTER ROTOR HAVING RECTANGULAR BLADES WITH -8° TWIST

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SUMMARY

Theoretically derived charts are presented for prediction of profile drag-lift ratios of helicopter rotors having rectangular blades with -8° twist. Conditions for onset of blade-section stalling are shown in the charts.

PURPOSE

Theoretically derived charts for predicting the profile drag-lift ratio of a helicopter rotor having untwisted rectangular blades were presented in reference 1. Similar charts have been prepared for the case of -8° twist (blade pitch angle at tip 8° lower than at root, with linear variation between). These charts have not previously been published owing to the expectation of incorporating refinements to the theory, particularly those refinements indicated in reference 2 to be desirable for extreme values of rotor angle of attack and for relatively high tip-speed ratios.

Owing to frequent requests by the users of reference 1 for the -8° charts in their present form, however, they are presented as figure 1 of this paper.

SYMBOLS

P/L	shaft-power parameter (see ref. 1)
$(D/L)_o$	profile drag-lift ratio

α_o	angle of attack at rotor-blade section as measured from angle of no lift
$\alpha_{(1.0)(90^o)}$	blade-element angle of attack at tip at azimuth of 90^o
$\alpha_{(1.0)(270^o)}$	blade-element angle of attack at tip at azimuth of 270^o
$\alpha_{\left(u_T=.4\right)\left(270^o\right)}$	blade-element angle of attack at 270^o azimuth at radial position where tangential velocity equals 0.4 times the rotational tip speed
c_{d_o}	profile drag coefficient of rotor blade section
θ_{75}	blade pitch at 75 percent radius
μ	tip-speed ratio
θ_1	difference between hub and tip pitch angles
C_L	rotor lift coefficient
σ	rotor solidity

DISCUSSION

The explanation given in reference 1 concerning the use of this type of chart, including the use of the "limit lines" indicating onset of effects of blade-section stalling, is believed adequate for use with these charts. The significance of the results shown for the twisted blades, as compared with the results of reference 1 for the untwisted blades, is illustrated in the appendix by means of a study of a sample helicopter. Comparisons of theory and experiment concerning effects of twist are given in references 3 and 4.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 24, 1953.

APPENDIX

SUMMARY OF EFFECTS OF TWIST IN FORWARD FLIGHT

FOR A SAMPLE HELICOPTER

The following sample study is included to illustrate the theoretical effects of blade twist in forward flight. For the sample case employed, results are shown for additional values of blade twist to indicate the trends beyond the two values for which charts are available. Values for blade flapping motion are also included. Both the additional twist values and the flapping values were obtained from calculations based on reference 5.

Sample Helicopter

The helicopter characteristics used in the sample calculations are as follows:

Gross weight, lb	2700
Rotor diameter, ft	41
Solidity	0.045
Blade plan form	Rectangular
Rotor-blade mass constant, γ	15
Tip speed, fps	540
Parasite drag area, D/q, sq ft	15

The blades are assumed to be "semismooth," the profile-drag polar being represented by the equation employed in references 1 and 5, namely

$$c_{d_o} = 0.0087 - 0.0216\alpha_o + 0.400\alpha_o^2$$

This design is not intended to represent an optimum choice of parameters, but inasmuch as the thrust coefficient-solidity ratio is within the range covered by current designs, the effects of twist indicated for this example may be considered to be typical.

Level Flight

The effects of twist for the level-flight condition follow:

(a) Effect on maximum speed V_{max} in miles per hour as limited by excessive blade-section angles of attack (limiting angles chosen as in reference 1):

Twist angle (deg)	V_{max} (mph)	
	$\alpha_{lim} = 12^{\circ}$	$\alpha_{lim} = 16^{\circ}$
8	72	104
0	93	119
-8	112	131
-16	126	---

Exact values are not available, but it should be remarked that at V_{max} the -16° twist value invites negative angles of attack at the advancing tip to a degree which might prove undesirable.

(b) Reduction in power for operation at the stated tip speed (540 fps), as compared with no twist:

Twist angle (deg)	Reduction in power (percent)
8	-4
-8	2
-16	2

These values are essentially constant for speeds from 50 miles per hour up to the limiting speed.

(c) Reduction in power for operation at a limiting blade-section angle of attack of 12° at the tip speed required by this condition:

Twist angle (deg)	Reduction in rotor shaft power (percent)
8	-10
-8	4 to 5
-16	3 to 5

These values apply to speeds from 50 miles per hour up to the limiting values.

Autorotation

Calculations of rate of descent for the sample helicopter operating at 50 and 110 miles per hour, and operating at 540 feet per second tip speed, 450 feet per second tip speed, and at the tip speeds for limiting angles of attack of 12° and 16°, respectively, were made. Results of these calculations are summarized in the following table, which shows the changes in rate of descent as compared with the zero-twist case (positive values indicate increased rate of descent):

Twist angle (deg)	Change in rate of descent (percent)
8	3 to 5
-8	1.5 to -1.5 (average, -0.5)
-16	5 to -2.5 (average, 0.5)

Intermediate values of forward speed or tip speed would be expected to yield results within these ranges.

Climb

At or near the best climbing speed, operation at the tip speed for a limiting angle of attack of 12° shows the following changes in rate of climb when the rotor shaft horsepower is fixed at 200 (positive values indicate increased rate of climb):

Twist angle (deg)	Change in rate of climb (percent)
8	-10
-8	7
-16	11

If operation at a tip speed of 540 feet per second is assumed instead of operation at the limiting angle, the changes in rate of climb are reduced to one-third of those just given.

Blade Motion

Calculations of blade motion following the method given in reference 5 indicate that negative twist results in appreciable reduction in coning angle and slight reductions in the first and second harmonics of the flapping motion. Values calculated for the present example for level flight at a tip-speed ratio of 0.3 are:

Twist angle (deg)	a_o	a_1	b_1	a_2	b_2
0	0.156	0.114	0.064	0.009	-0.004
-8	.140	.112	.058	.008	-.004
-16	.125	.110	.052	.007	-.004

The coefficients given are those in the Fourier series for flapping angle

$$\beta = a_o - a_1 \cos \psi - b_1 \sin \psi - a_2 \cos 2\psi - b_2 \sin 2\psi$$

where ψ is the azimuth angle. Values given are in radians. In view of the adverse indications of the performance calculations, values for 8° twist have been omitted.

REFERENCES

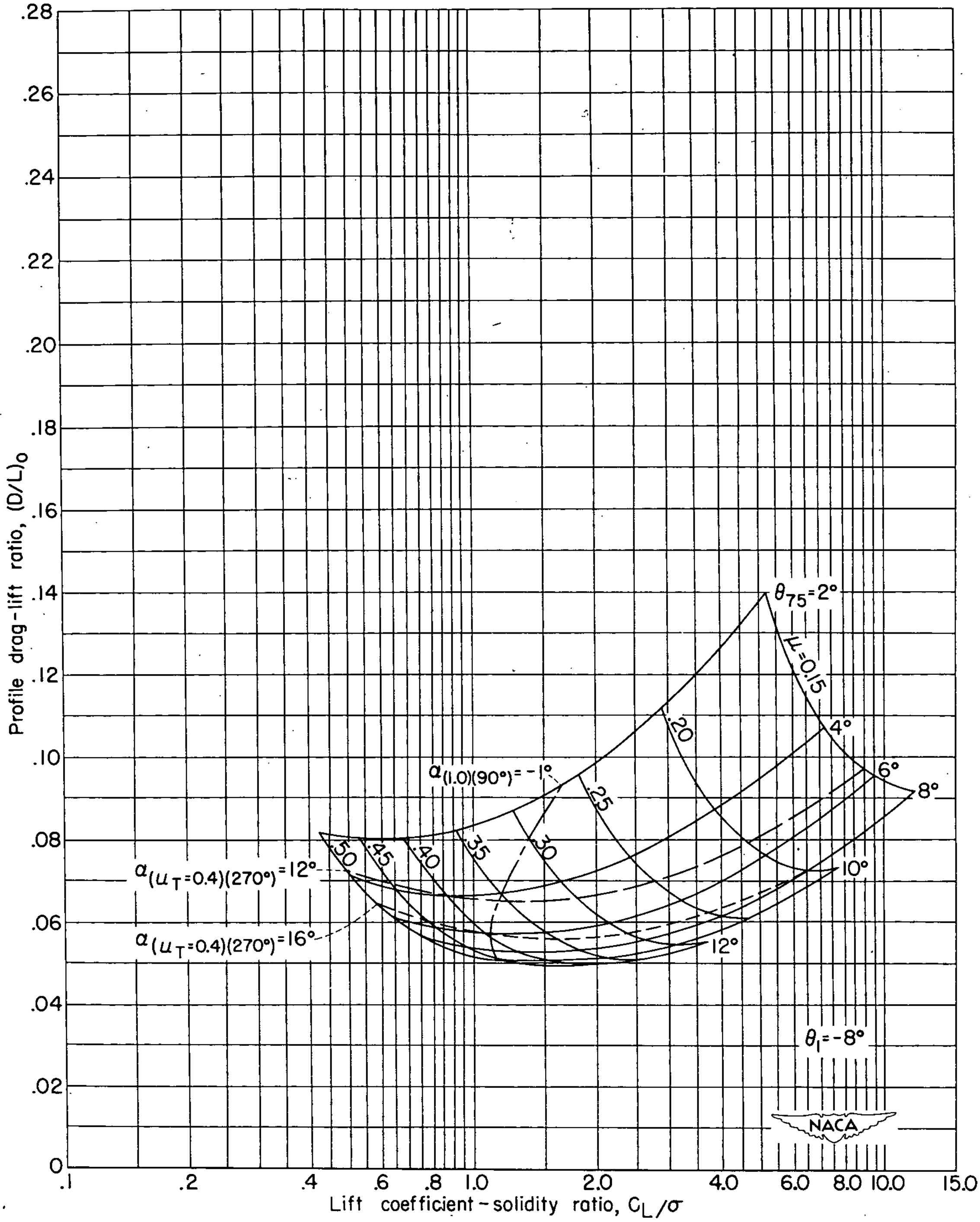
1. Bailey, F. J., Jr., and Gustafson, F. B.: Charts for Estimation of the Characteristics of a Helicopter Rotor in Forward Flight. I - Profile Drag-Lift Ratio for Untwisted Rectangular Blades. NACA WR L-110, 1944. (Formerly NACA ACR L4H07.)

2. Gessow, Alfred, and Crim, Almer D.: An Extension of Lifting Rotor Theory To Cover Operation at Large Angles of Attack and High Inflow Conditions. NACA TN 2665, 1952.

3. Gessow, Alfred: Flight Investigation of Effects of Rotor-Blade Twist on Helicopter Performance in the High-Speed and Vertical-Autorotative-Descent Conditions. NACA TN 1666, 1948.

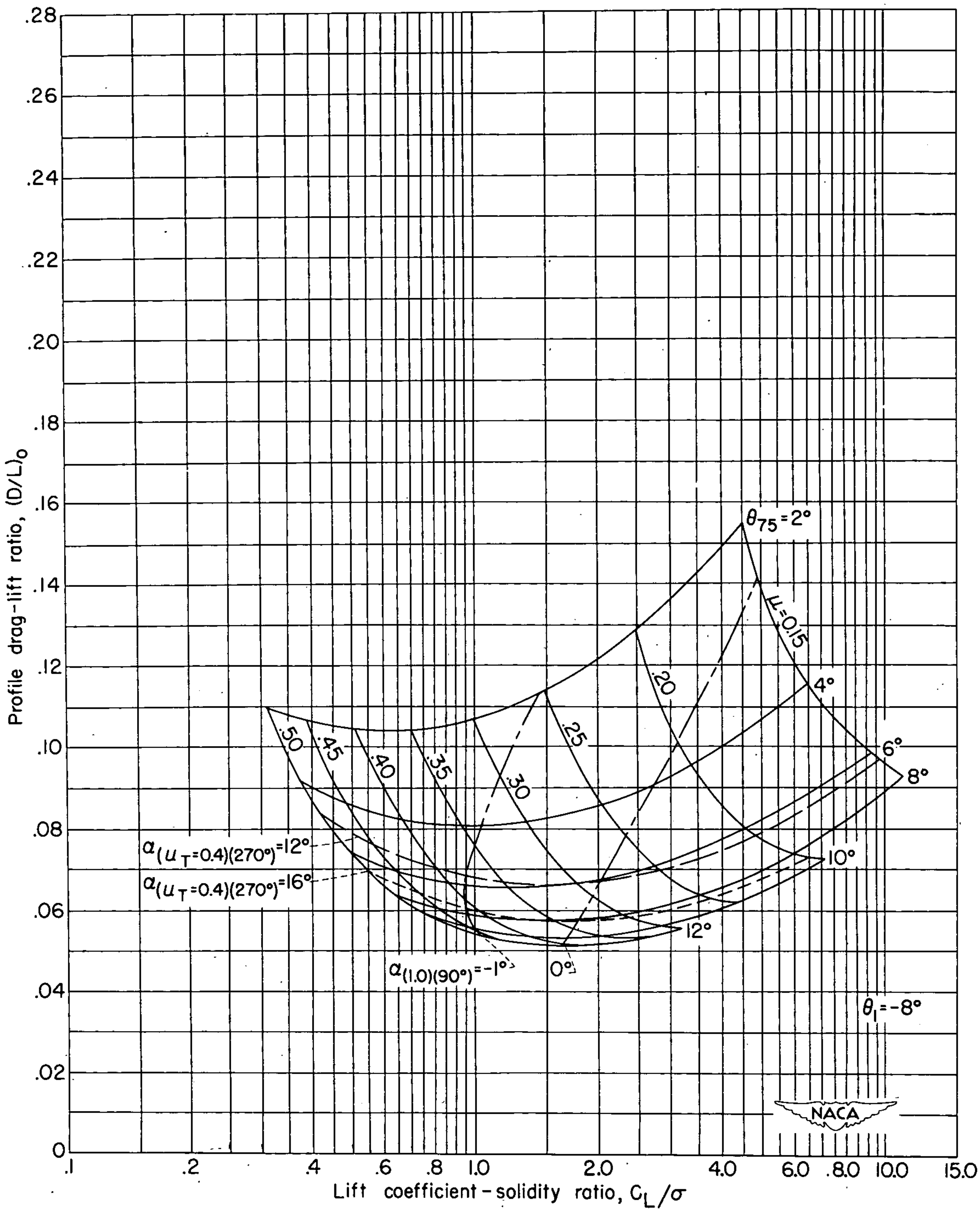
4. Carpenter, Paul J.: Effects of Compressibility on the Performance of Two Full-Scale Helicopter Rotors. NACA Rep. 1078, 1952. (Supersedes NACA TN 2277.)

5. Bailey, F. J., Jr.: A Simplified Theoretical Method of Determining the Characteristics of a Lifting Rotor in Forward Flight. NACA Rep. No. 716, 1941.



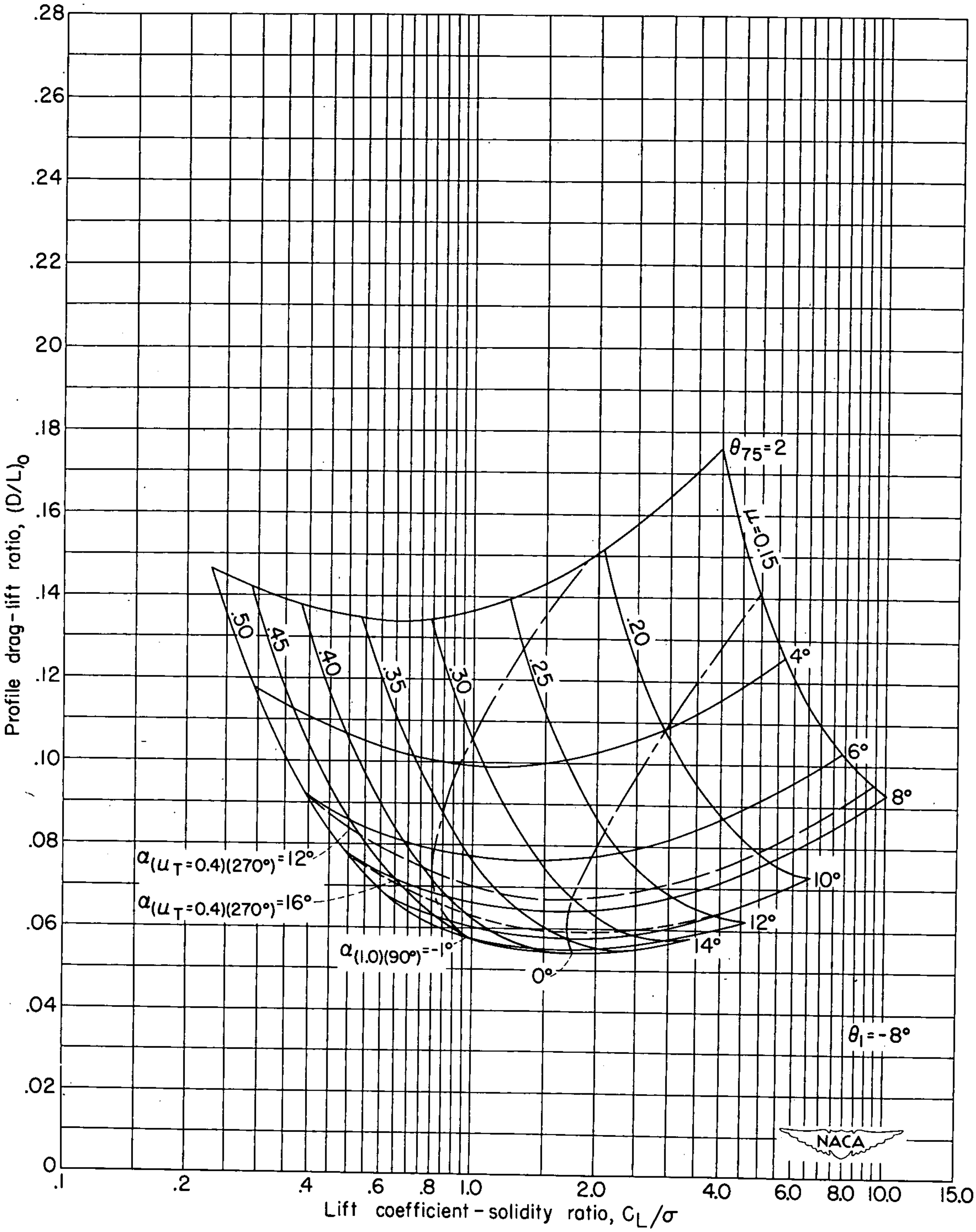
(a) P/L = 0.

Figure 1.- Profile drag-lift ratio for rotor with -8° twist.



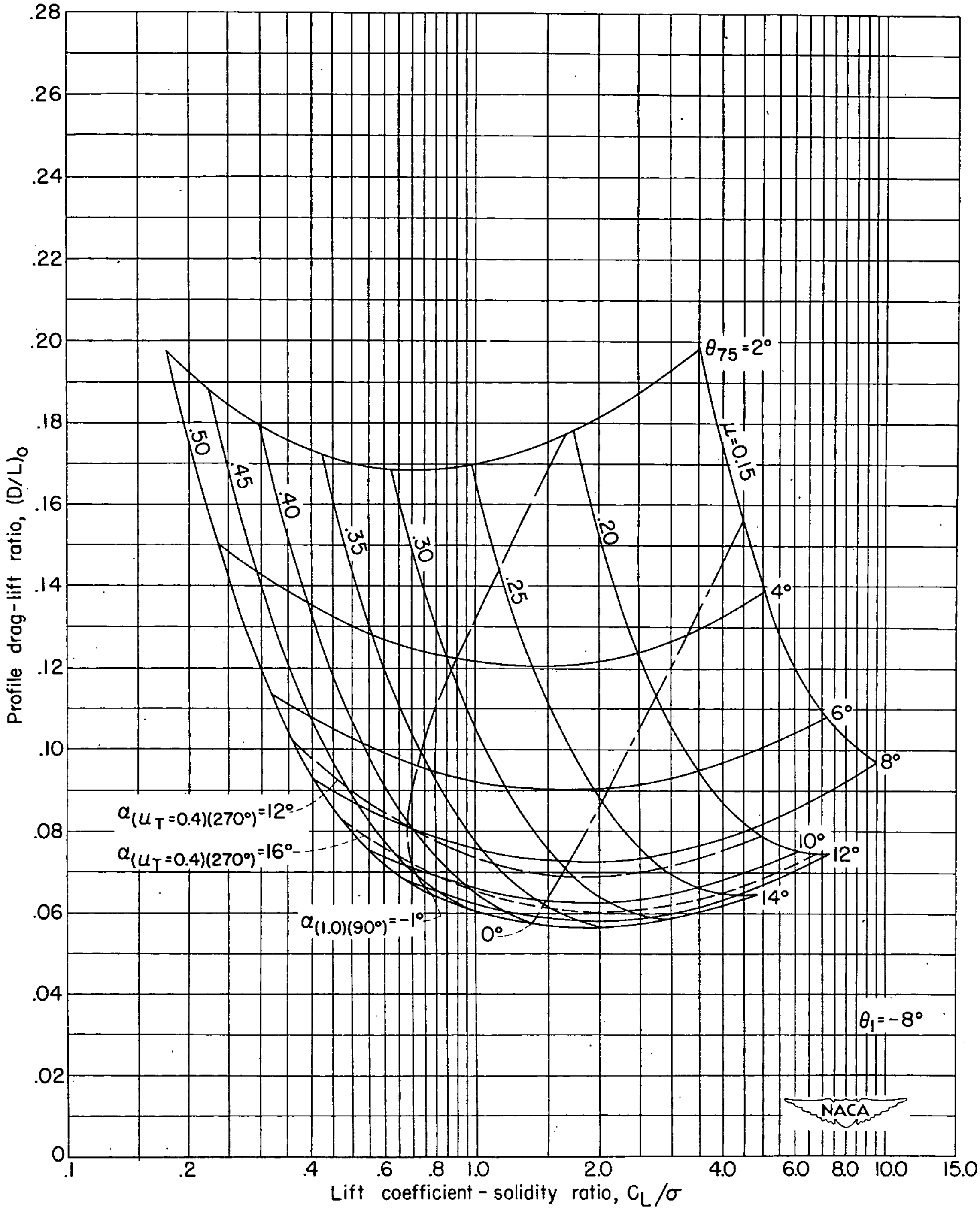
(b) P/L = 0.05.

Figure 1.- Continued.



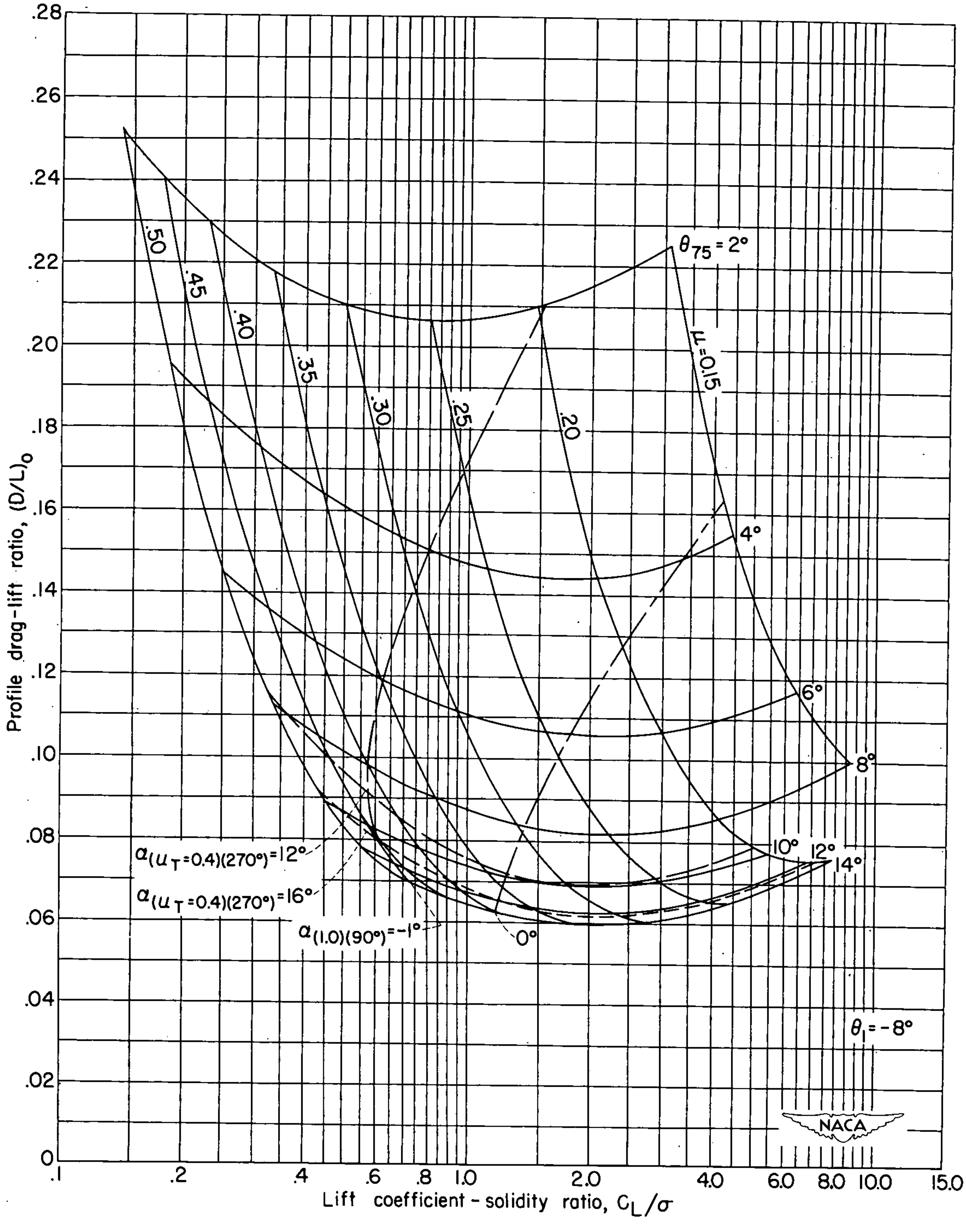
(c) P/L = 0.10.

Figure 1.- Continued.



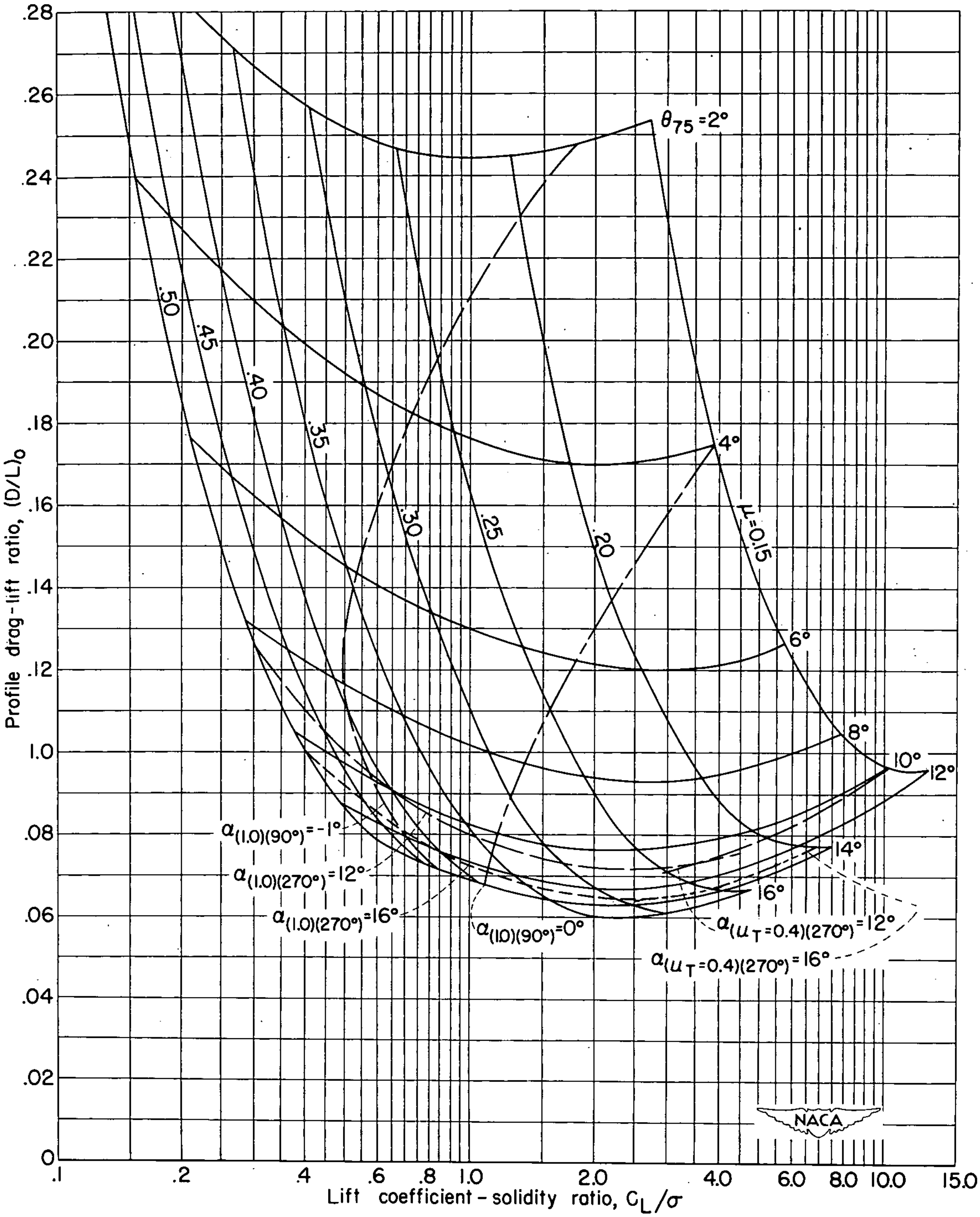
(d) P/L = 0.15.

Figure 1.- Continued.



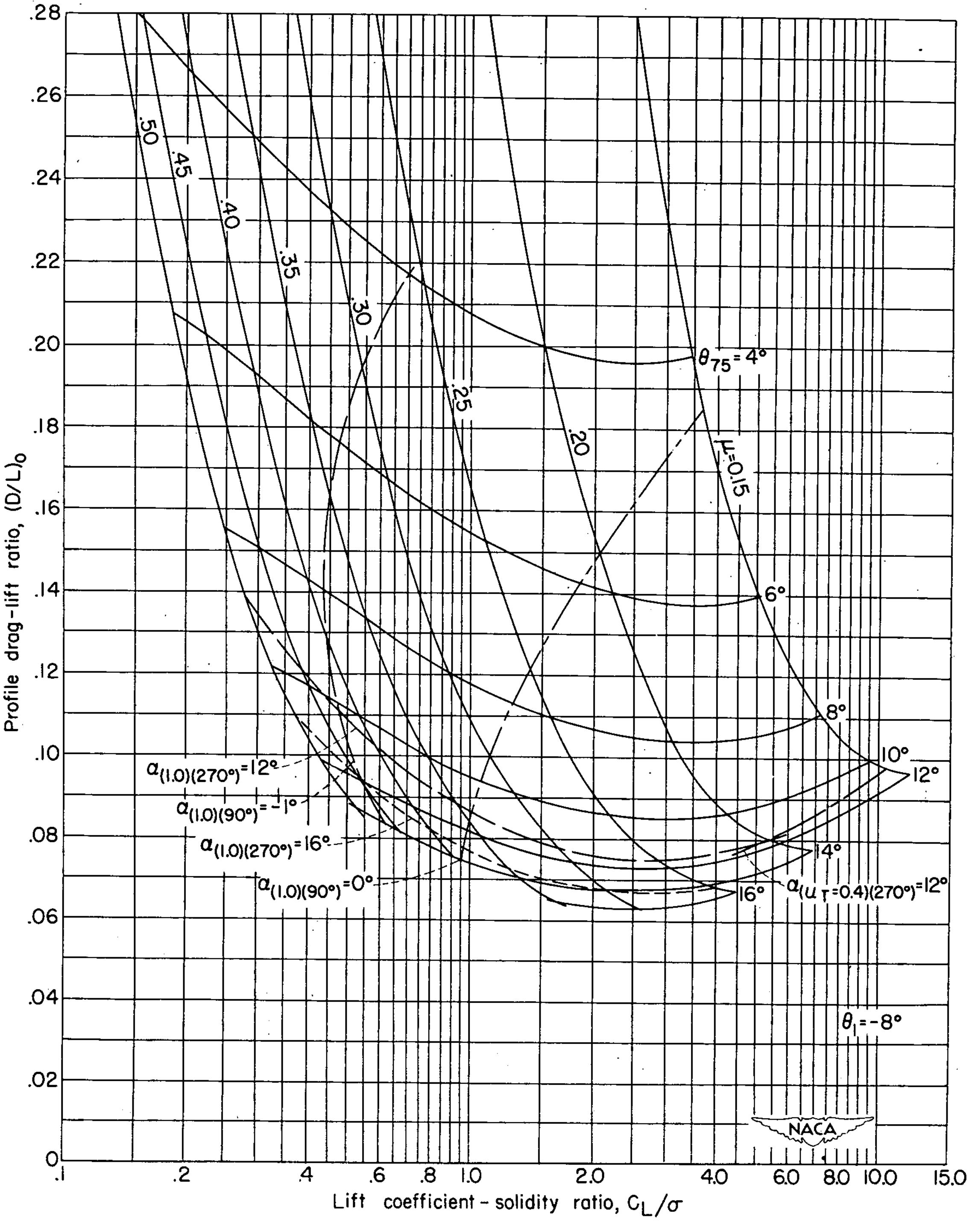
(e) P/L = 0.20.

Figure 1.- Continued.



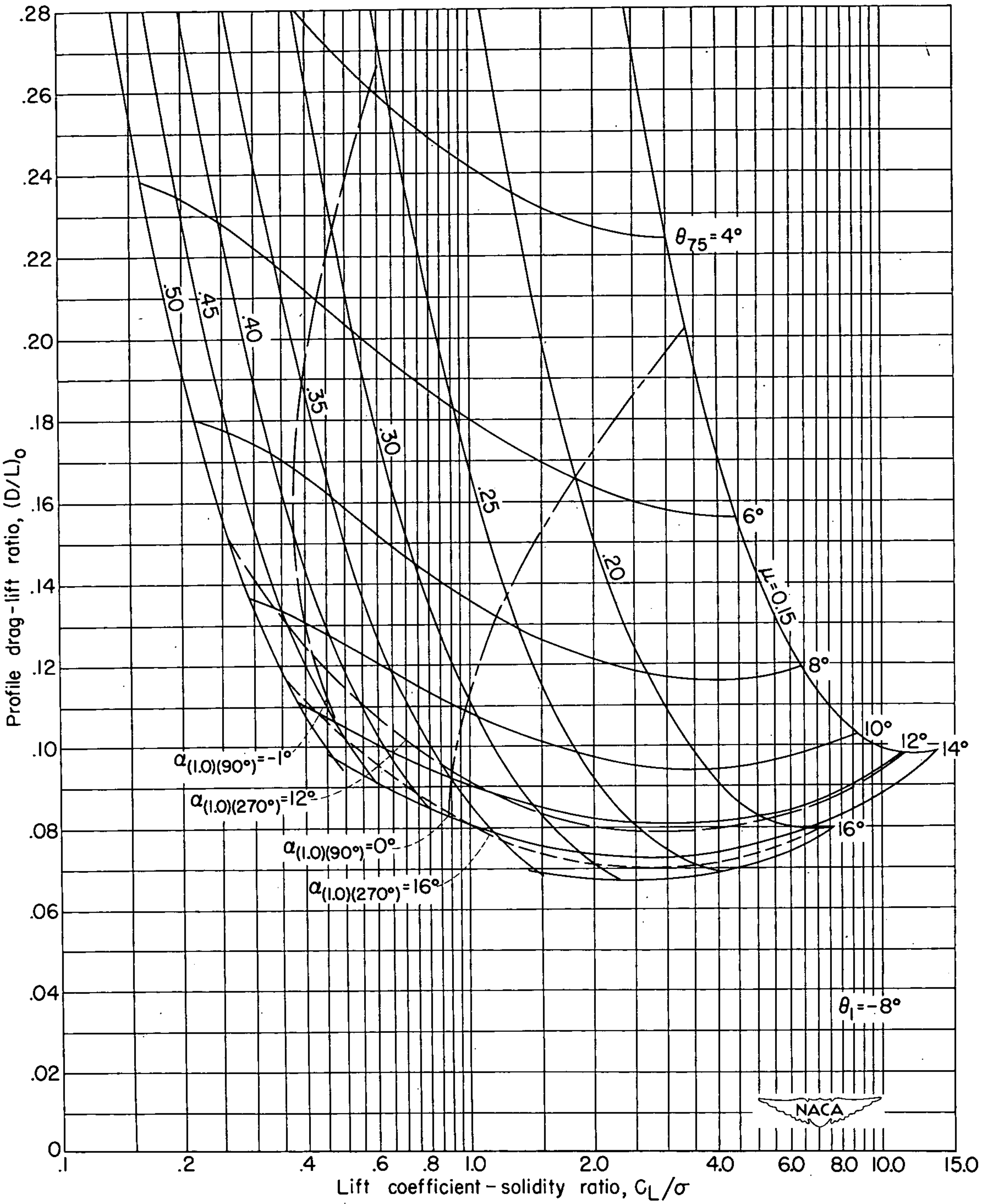
(f) P/L = 0.25.

Figure 1.- Continued.



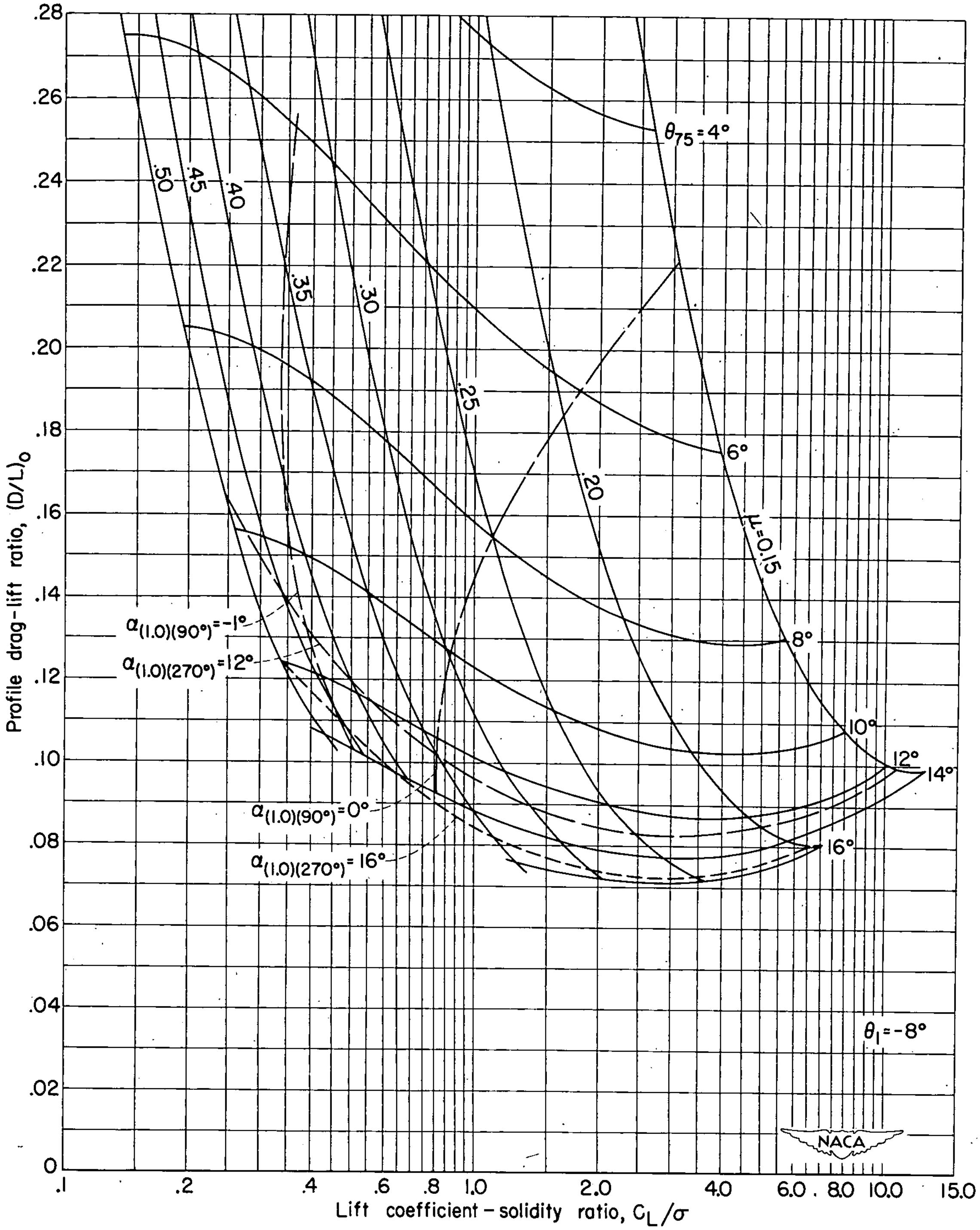
(g) P/L = 0.30.

Figure 1.- Continued.



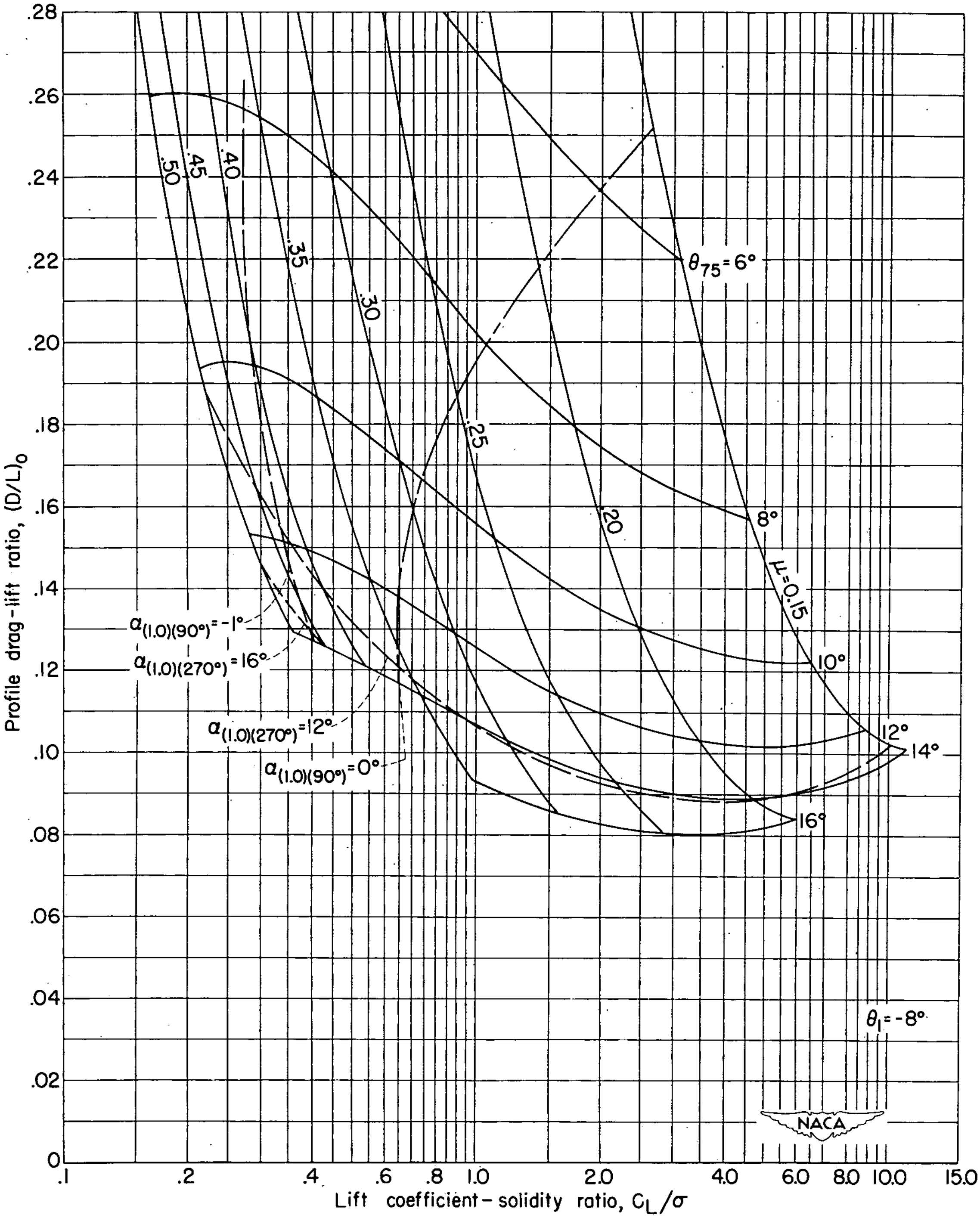
(h) P/L = 0.35.

Figure 1.- Continued.



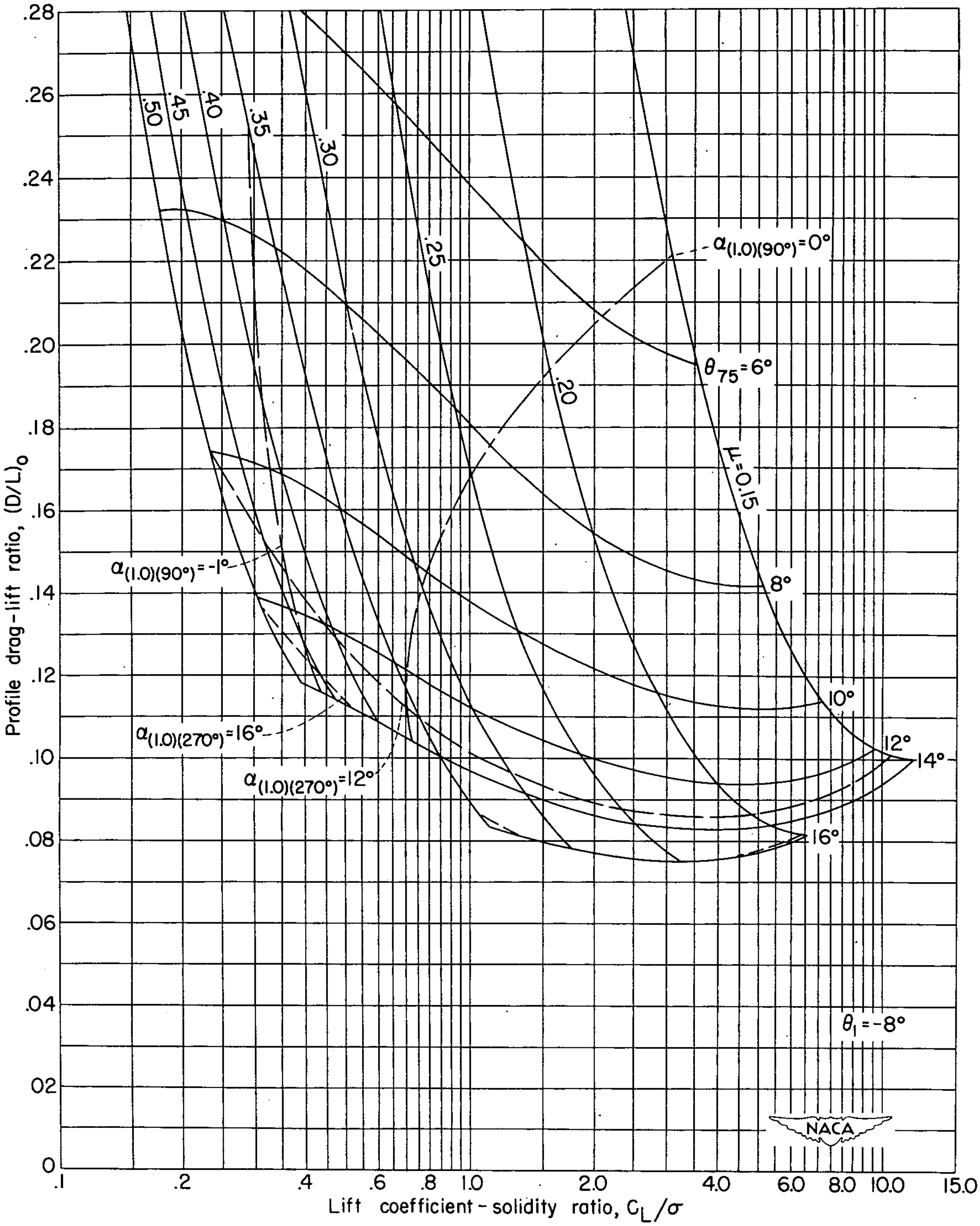
(i) P/L = 0.40.

Figure 1.- Continued.



(k) P/L = 0.50.

Figure 1.- Concluded.



(j) P/L = 0.45.

Figure 1.- Continued.